Application of Ocean Observing System Simulation Experiments for Improving Hurricane Forecasting

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MAPP Webinar
Tropical Climate Extremes
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Overview

- **Relevant MAPP Project: "Mesoscale Variability in the Gulf of Mexico and its Importance in Climate Extremes over North America"**
  - PI: Igor Kamenkovich (RSMAS, University of Miami)
  - Co-I's: Villy Kourafalou (RSMAS, U/ of Miami), George Halliwell (NOAA/ AOML/PhOD)
  - Study the impact of mesoscale ocean variability on upper-ocean thermal anomalies that can impact climate extremes over North America
    - One emphasis is on hurricanes (individual storms and seasonal)
  - Project is in its very early stages
- **Present Talk:**
  - Demonstrate that accurate monitoring of the Atlantic warm pool, including ocean mesoscale structure within the warm pool region, is important for hurricane forecasting, both seasonally and for individual storms
    - Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) can evaluate the impacts of present and future ocean observing systems, respectively, for the purpose of monitoring the warm pool
  - Describe new ocean OSE/OSSE system, including initial test results
  - Discuss how OSEs and OSSEs will be used to evaluate present and future ocean observing systems for Atlantic warm pool monitoring

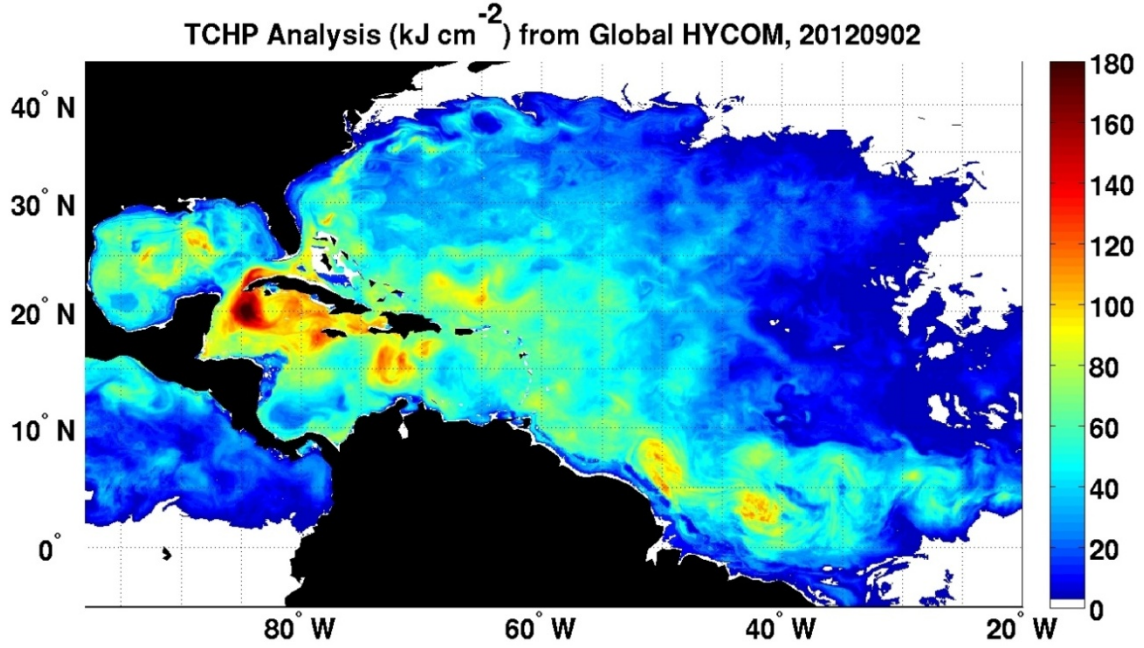
Atlantic Warm Pool and Hurricane Intensity Forecasting

- **Importance of warm pool structure for hurricane intensity**
  - It is not SST, but the thickness of the warm surface layer (>26ºC) that is critically important
    - 70-90% of SST cooling beneath storms results from entrainment of cold water into the deepening mixed layer
    - Thick (thin) layer of warm water inhibits (increases) storm-forced SST cooling
      - <1ºC in regions with thickest warm layers
      - Up to several degrees Celsius where warm layers are thin
      - Thin warm layers make it difficult for major hurricanes to form
    - Initialization errors produce large errors in forecast SST cooling
- **Importance of ocean observations**
  - They constrain the three-dimensional upper-ocean structure in data-assimilative ocean analysis products
    - e.g., Mercator, global HYCOM
    - Provide near-real-time analyses of warm pool region during hurricane season
    - These analyses will be used in the near future to initialize the ocean component of coupled hurricane forecast models
  - OSEs and OSSEs can be employed to determine if the existing ocean observing system is adequate or should be enhanced to improve warm pool monitoring

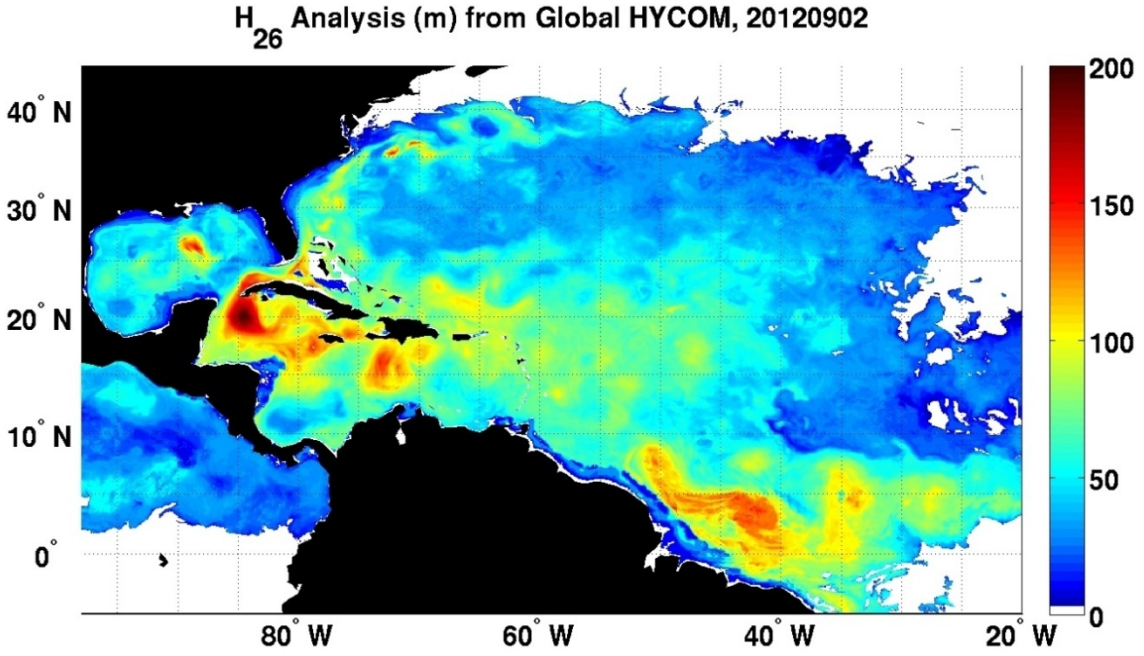
Maps From the Navy Global HYCOM Analysis

Tropical Cyclone Heat Potential (TCHP)

$$\mathrm{TCHP} = c_p \int_0^{D_{26}} \rho \left[T(z) - 26 \right] \, dz,$$



26ºC Isotherm Depth



OMOC Ocean OSSE System

- **Joint AOML/CIMAS Ocean Modeling and OSSE Center**
  - Co-directors: G. Halliwell (NOAA/AOML) and V. Kourafalou (UM/RSMAS)
  - Advisor: R. Atlas (NOAA/AOML)
- **OSSE System**
  - Based on HYbrid Coordinate Ocean Model (HYCOM)
    - Two different configurations used for Nature Run and the ocean forecast model
  - Uses a new research ocean data assimilation system
    - Tendral Statistical Interpolation System (T-SIS)
    - Comparable performance compared to the Navy global HYCOM nowcast-forecast system
  - Uses strict design criteria and rigorous evaluation techniques developed for atmospheric OSSE systems that have not yet been completely implemented for the ocean
    - The evaluation determines *a-priori* that the system provides valid observing impact assessments
  - Initially configured in a regional Gulf of Mexico domain
  - Will soon be expanded to Atlantic warm pool domain

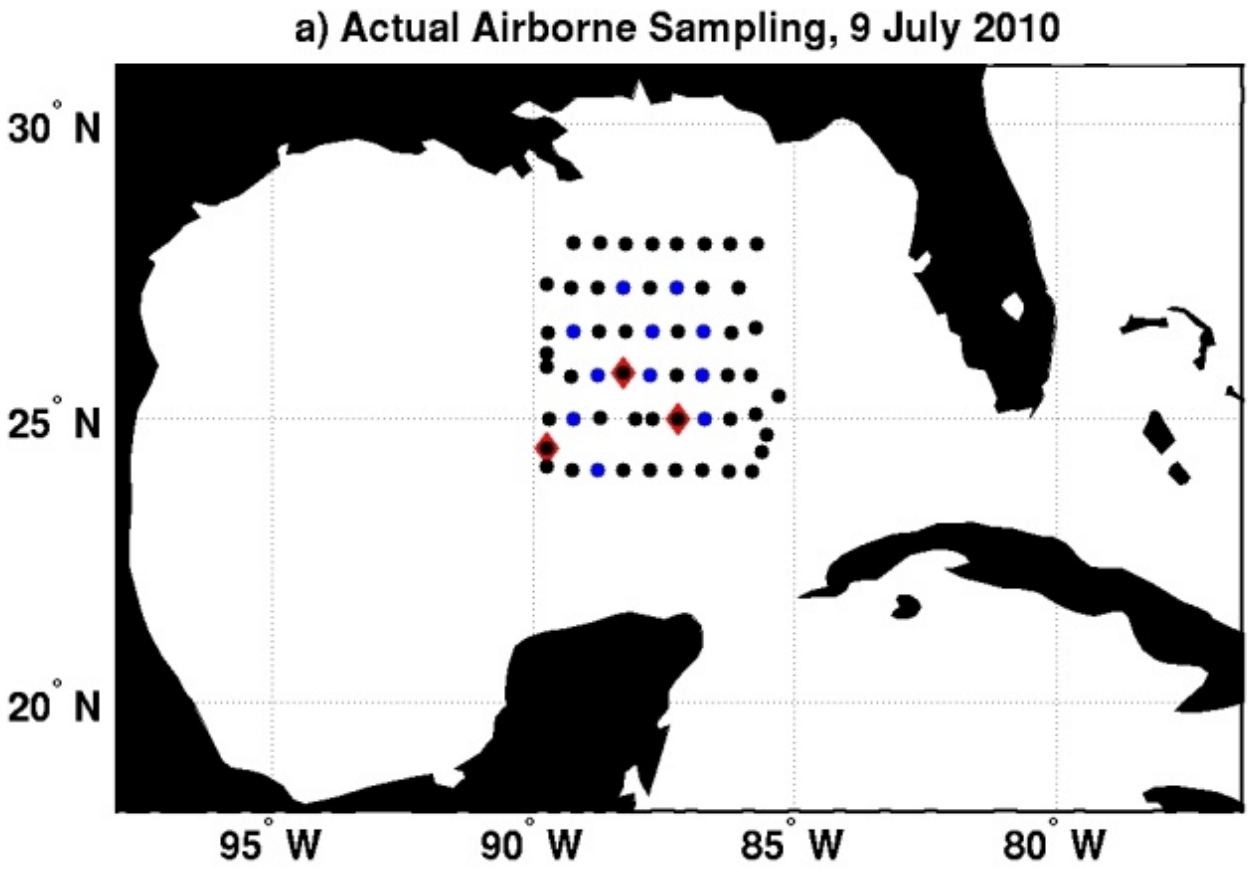
OSEs and OSSEs

- **OSE**
  - Perform win data-assimilative experiments
    - One assimilates all observations
    - One denies only the observing system of interest
  - Impact determined by increased analysis and forecast errors
- **OSSE**
  - Same procedure as OSEs except for assimilating synthetic observations (with realistic errors added) simulated from a Nature Run (NR)
  - Permits the following:
    - Impact of new operational observing systems
    - Impact of changing the deployment of existing systems
    - Experimental design studies
- **OSSE system is evaluated by performing OSEs, and then performing OSSEs that are identical except for the use of synthetic observations**
  - The system is validated if the same impact assessments are obtained from corresponding OSEs and OSSEs

OSSE System Validation in the Gulf of Mexico

- Evaluated against DWH airborne profile surveys
  - Nine flight days between 8 May and 9 July 2010
    - Typical flight pattern (9 July) shown below

AXBT (black dots)
AXCTD (red diamonds)
AXCP (blue dots)



OSSE System Validation in the Gulf of Mexico (cont'd)

- **OSEs**
  - Four one-year experiments using DA model with daily update cycle
    - 1. Assimilate all observations
      - Three altimeters (Jason1, Jason2, Envisat)
      - MCSST SST
      - *In-situ* SST (ship, surface buoy, surface drifter)
      - Ship XBT profiles
    - 2. Deny two of three altimeters
    - 3. Deny all observations (unconstrained)
- **OSSEs**
  - Experiments OSSE1, OSSE2, OSSE3 identical to OSE1, OSE2, and OSE3, but assimilate synthetic instead of real observations

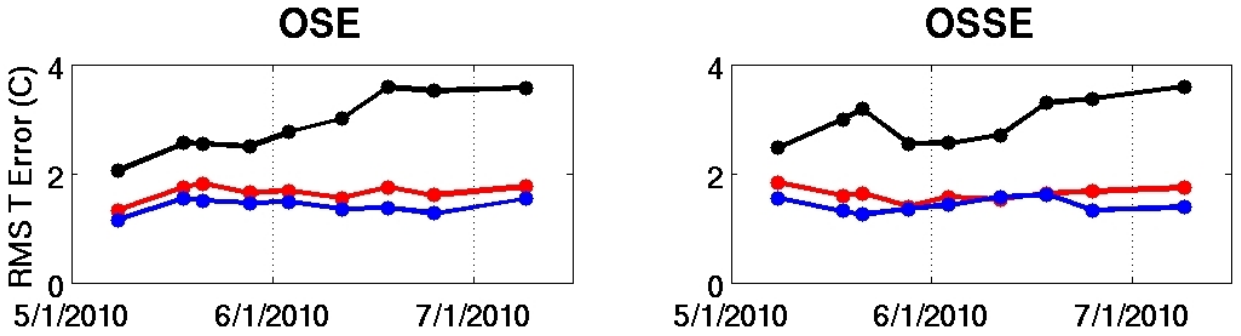
OSSE System Validation in the Gulf of Mexico (cont'd)

Results:
1. Same impact assessments obtained
2. Calibration is not required.

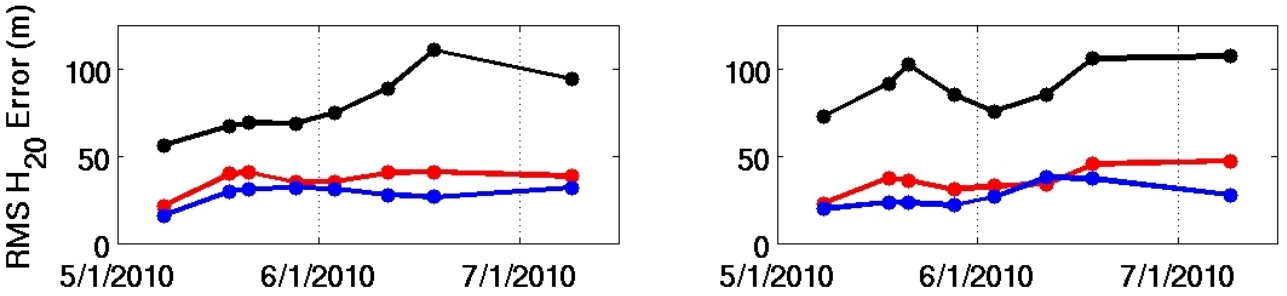
1. Assimilate all observations
2. Deny two of three altimeters
3. Deny all observations (unconstrained)

RMS Errors

Temperature, 0 – 250 m, from all profiles on 9 flight days

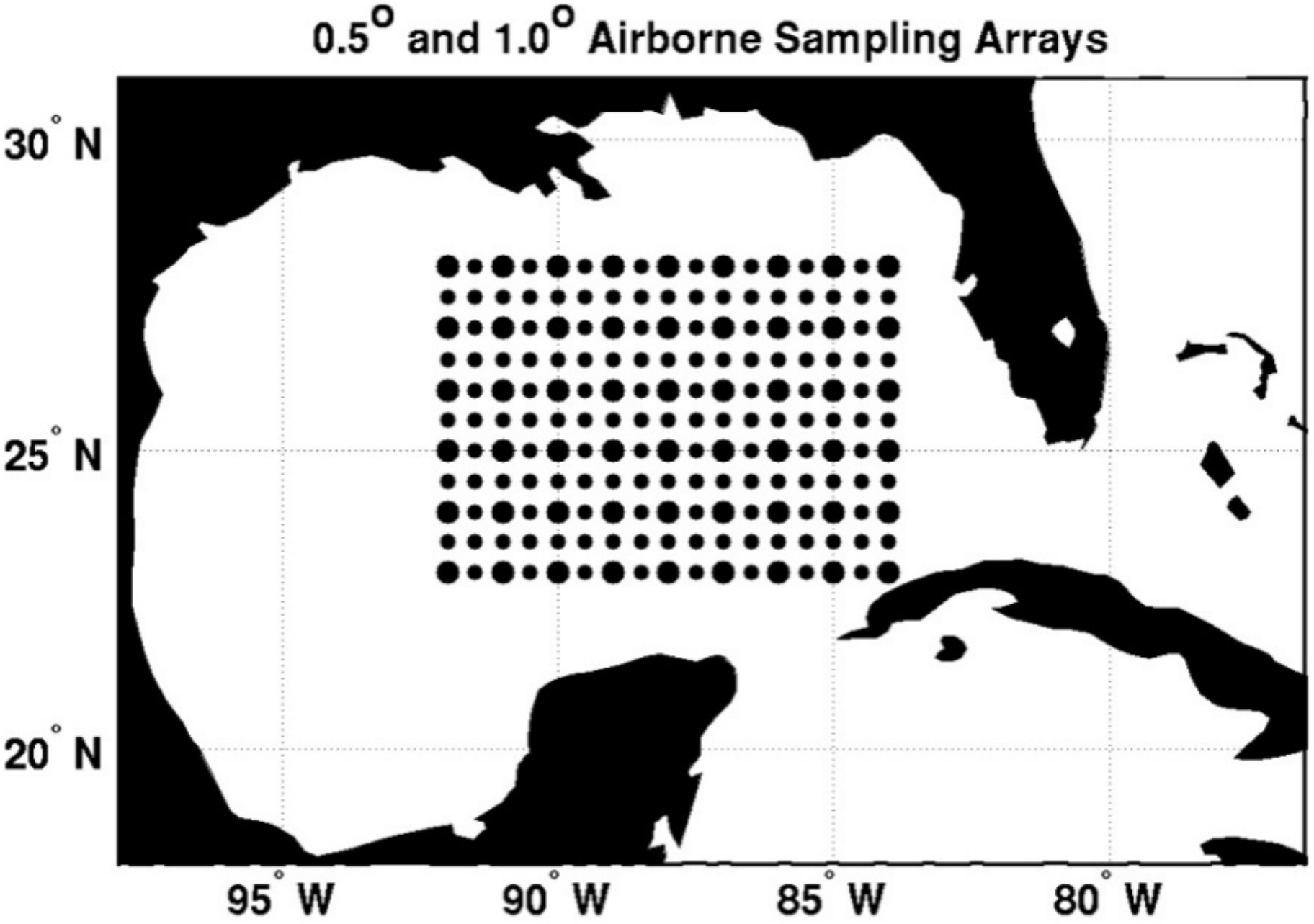


H_{20} at all profile locations on 9 flight days



OSSE Example

- **Impact of horizontal profile resolution in rapid-response airborne surveys for improving ocean forecast model initialization**
  - Four-day analysis cycles run at 7-day intervals from May - October 2010
  - The following observations are assimilated daily over all four days
    - Altimetry (Jason-1, Jason-2, Envisat)
    - Satellite SST (MCSST)
    - *In-situ* SST (ship, surface drifter, surface buoy)
    - Ship XBT measurements
    - Airborne profiles
      - 1000 m synthetic AXCTDs used for the horizontal resolution test
- **Three experiments**
  - Assimilate all observations with airborne profiles on 0.5º grid
  - Assimilate all observations with airborne profiles on 1.0º grid
  - Assimilate all observations except airborne profiles

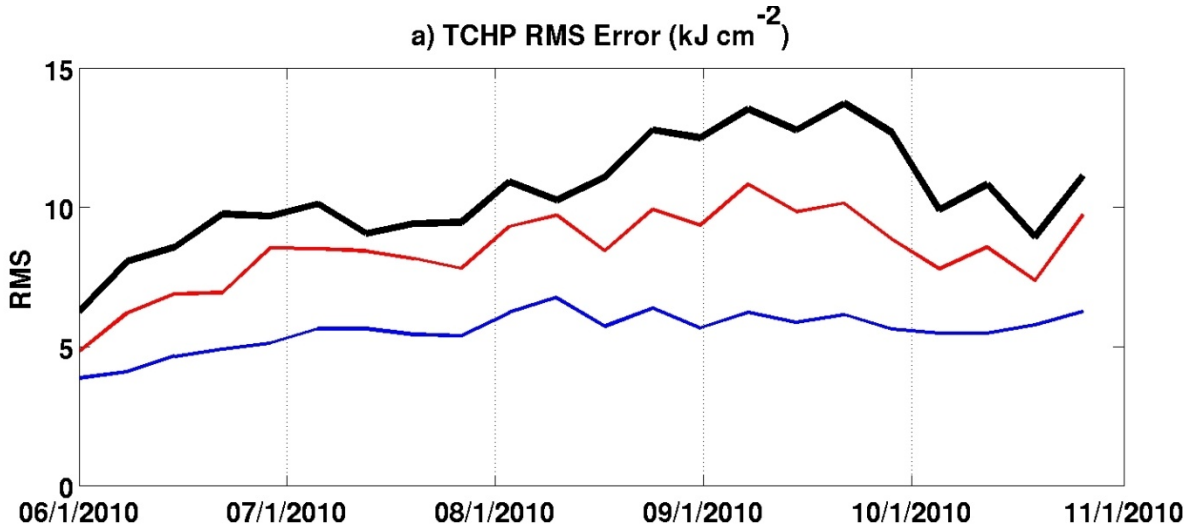

0.5° and 1.0° Airborne Sampling Arrays
30° N
25° N
20° N
95° W
90° W
85° W
80° W

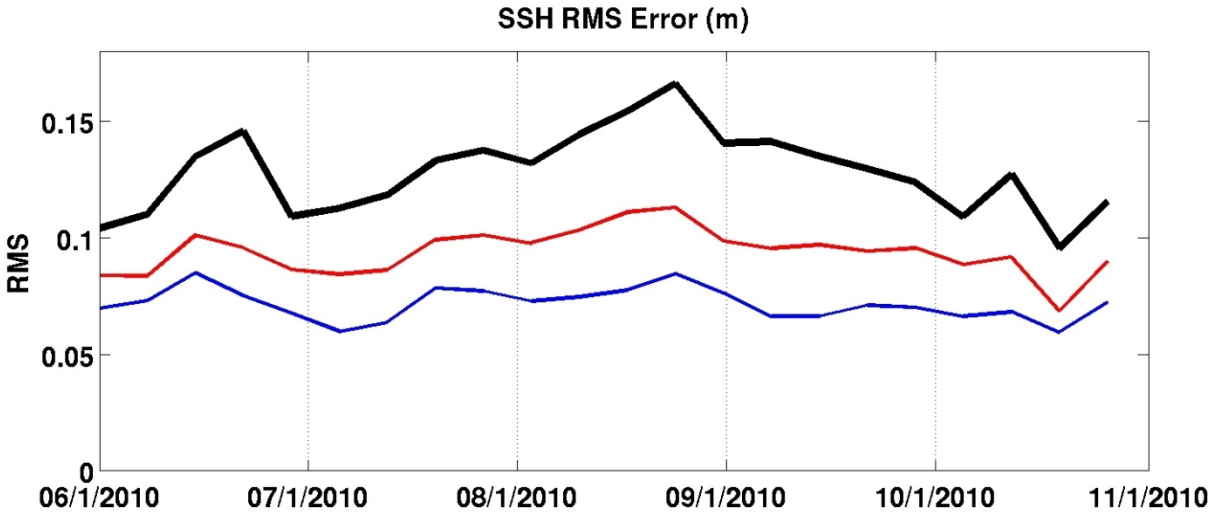
Impact of Horizontal Resolution on RMS Errors

All obs. with 0.5º profile grid

All obs. with 1.0º profile grid

All obs. except airborne profiles



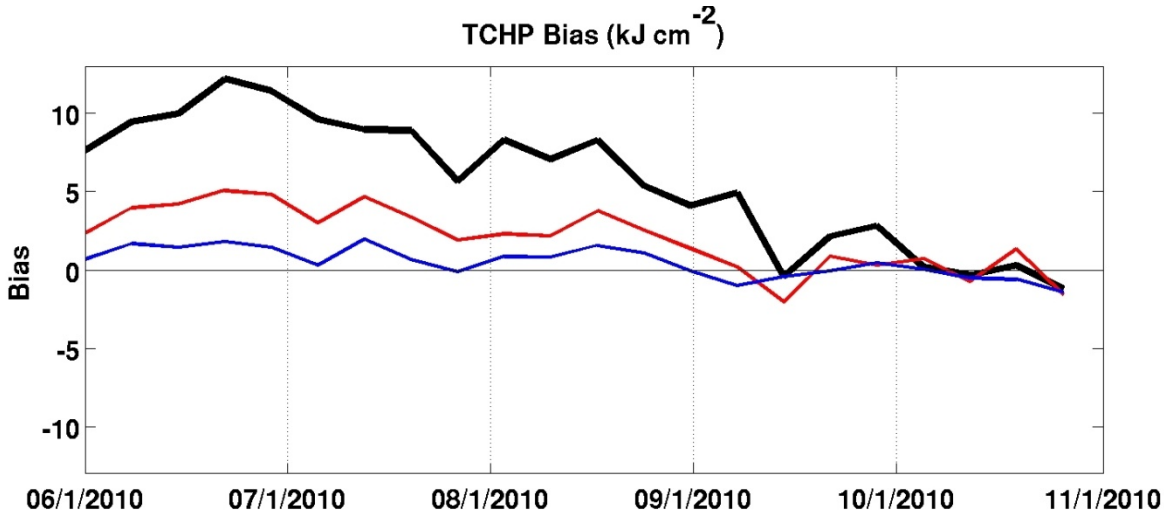


Impact of Horizontal Resolution on Mean Bias

All obs. with 0.5º profile grid

All obs. with 1.0º profile grid

All obs. except airborne profiles



OSSEs for Atlantic Warm Pool Domain

- **The OSSE system will next be set up in a larger Atlantic domain containing the warm pool region**

- **Questions to be addressed using OSEs and OSSEs**
  - Impact of existing ocean observing systems using OSEs
    - Surface drifters
    - Argo profiles
    - XBT transects
  - Impact of new or enhanced ocean observing systems using OSSEs
    - Adding thermistor chains to surface drifters and surface meteorological buoys
    - Adding XBT transects, particularly in the Caribbean Sea and Gulf of Mexico where Argo floats are rarely present.
    - Powered gliders, particularly in the Caribbean and Gulf